Contact cleaning for defect reduction in 21st century PCB manufacture

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INTRODUCTION

Contact cleaning has become well established as a technology for removing particles of contamination from surfaces to provide increased yields through defect minimisation. Originally developed in the early 1980s to remove particles from PCB glass photo-tools before lamination with protective film its applications have widened to include many types of rigid, flat materials and more recently into cleaning flexible substrates both on a sheet and roll to roll basis. As the marketplace demand for smaller, lightweight electronic devices grows the materials used within these devices have become thinner and much more flexible. The flimsy nature of these materials poses challenges for traditional contact cleaning technology, particularly where they are processed in sheet format. This paper reports some of the research work which has been done to overcome these challenges and allow contact cleaning to remain a key technology for defect reduction in PCB manufacture.

The basic concept, shown below in Figure 1, is that a roller, made from elastomer, runs over a flat surface and picks up any dry particles present on the surface. The elastomer roller simultaneously runs in contact with an adhesive roll which has the pressure sensitive adhesive coating on the outside of the roll instead of on the inside which is how most adhesive tape is wound. The particles of contamination are transferred to the adhesive surface where they are permanently captured, while the surface of the elastomer roller is always kept completely clean. When the adhesive surface is full of contamination the outer sheet of the adhesive roll is removed and disposed of.

Initial applications for the technology included cleaning both the inner and outer layers of PCBs during imaging and before lamination, as well as the finished PCB. The size of particle which could cause a defect was large due to the substantial conductor width and spacing.

At this time there was a belief that softer elastomers cleaned better because they deformed around the particle of contamination. As competition increased, other companies produced cleaning rollers based on different elastomers and rubbers. Tests were done on the cleaning efficiency of different rollers and it became clear from the results that cleaning efficiency was not related to the Shore hardness of the rubber as can be seen in Figure 2.

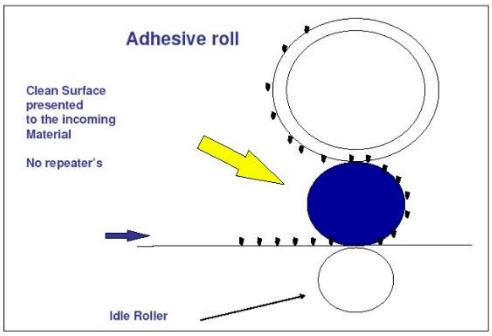

Figure 1.Basic Contact Cleaning Concept

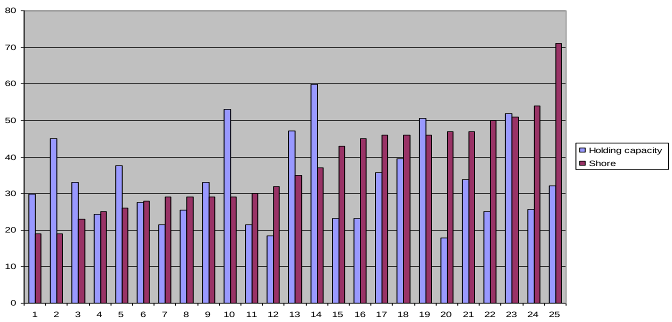

Figure 2. Cleaning Efficiency against Shore Hardness

As other factors must also be affecting the elastomer's ability to remove particles, a research project was started to try and identify those parameters and use them to develop better contact cleaning solutions. A key aim of the project was to understand the scientific principles behind effective contact cleaning.

SCIENCE OF CONTACT CLEANING

A literature search on contact cleaning revealed that very little research has been carried out on the removal of small particles from surfaces other than by fluid based technologies. The main focus of particle removal research has been into removing particles from silicon wafers using liquids, air or CO^2 snow. A few references to dry particle removal are found in work on improving the efficiency of xerographic processes where toner particles of a tightly defined shape and formulation are transferred by a roller to a paper surface. In contrast the types of particle and the surface on which they are situated are not controlled in contact cleaning. However several papers were found which detail the forces of adhesion holding particles onto surfaces and these formed the foundation for subsequent research work.

One of these papers by R. Kohli [1] identifies the key adhesion forces and also compares these forces as a function of particle size. Small particles can bond very strongly to surfaces through interactions such as covalent or ionic bonding, Van der Waals forces, hydrogen bonding, dipole-dipole, capillary forces and electrostatic interactions. Van der Waals forces dominate if the particles are small and spherical. Electrostatic forces become more important as the particles become larger and more irregular while a high humidity environment can increase the significance of capillary forces. A summary of force versus particle size taken from this paper is shown in Figure 3.

Work was done to analyse the equations defining the various forces of adhesion and a list of all the variable compiled, firstly, to identify the parameters which dominated the strength of the forces and, secondly, to select the variables which could easily be altered within the contact cleaning process. This is especially important as the exact properties of the surfaces to be cleaned and the type of particles which are to be removed are not under the control of the cleaning process. One specific parameter identified as being key to adhesion is the contact area between the surface and the particle, since the forces of adhesion are greater as they are applied over a larger area. Research was therefore focused on increasing the contact area between the elastomer roller and the particles.

J Walz and N Sung [2] paper on the effects of surface roughness on Van der Waals and electrostatic contributions to particle to particle interactions and particle adhesion by provided valuable insight and the research strategy taken was based on the diagram in Figure 4 from a paper by Beach, Drelich and Han[3]. The next phase of research was to use different methods to modify the texture of the elastomer roller surface to enable particles of contamination to nest within the surface structure thus increasing the contact area between the particle and the roller.

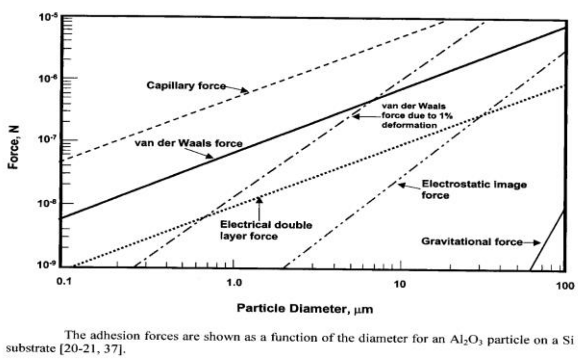

Figure 3. Adhesion Forces against Particle Diameter

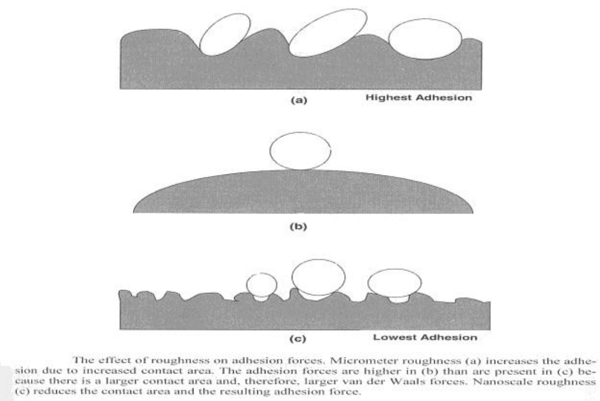

Figure 4. Diagram of Effect of Surface Roughness

EXPERIMENTATION

Initial experiments were done using an Instron Tensilometer to measure the adhesion forces between sections of elastomer cleaning rollers and different materials. The results are shown in Table1. These experiments report adhesion on a macro scale due to the large contact area and are relevant to the adhesion between the roller and a substrate but not particularly relevant to the adhesion between the roller and a particle. It can be seen from the results that while the levels of adhesion force vary significantly between material there is a similar trend for each material against the different elastomers.

To establish if there were differences when looking at adhesion on a micro level, a set of measurements was taken using Atomic Force Microscopy where probes of three different materials namely gold, silicon and polystyrene were contacted and then pulled off each of the elastomer samples. The results showed a big variation in each of the adhesion force as measured. As roughness has been shown to affect adhesion levels as part of the same suite of experiments the surface roughness of each of the elastomer samples was also measured using the AFM over three different dimensional scales. The results are shown in Tables 2 and 3.

The next stage was a range of experiments where different sizes and depths of textures were made on the surface of two elastomers, namely Panel and Nanocleen, which have different chemical compositions. The textured surfaces were then measured for cleaning efficiency using calibrated spherical particles of different materials. The measurement was done using a Partsens particle counter with a minimum resolution of 2 microns.

The first output of this research was a modified Nanocleen elastomer which was able to remove particles down to 100nm. This work was done as part of the Clean4Yield program which was tasked with upscaling the production of Organic Light Emitting Diode (OLED)s and Organic PhotoVoltaics (OPV). Verification of the cleaning efficiency was done on a range of substrates including silicon wafers, copper foil and polyester film.

Table 1. Macro Adhesion Forces (N/cm)

Rubber	Cu	Steel	Kapton	PET	PC
Soft	1.17	3.26	0.51	2.55	2.37
Panel	1.49	3.32	0.81	2.63	1.07
Film	0.63	0.81	0.34	1.68	1.4
F3	0.11	0.11	0.11	0.85	0.12
Nano	0.08	0.04	0.07	0.75	0.34

Table 2. Micro Adhesion Forces (nN)

Elastomer	Silica	Gold	Polystyrene
Soft	752+/-147	951+/-69	1027+/-109
Panel	848+/-113	823+/-160	847+/-214
Film	866+/-145	1152+/-125	1177+/-82
F3	1076+/-420	746+/-329	813+/-393
Nano	803+/-443	285+/-161	1073+/-629

Table 3. Surface Roughness at Different Scales

Rubber	1	2	3
Soft	2.169	11.143	38.582
Panel	7.355	13.493	23.467
Film	7.453	16.861	18.54
F3	31.009	49.085	98.334
Nano	3.616	1.4	6.292

STATIC CONTROL

Managing static charges and their associated electric fields has become a major concern in the manufacturing of electronics. While this is particularly true in electronics assembly where the chargers can damage sensitive devices it is also important in all other production processes as the charges can attract particles of contamination onto the surface of materials which can cause defects later in the production process or, more damaging still, during the product life.

Unfortunately the mechanism which makes contact cleaning so efficient at removing particles also, in traditional systems, makes it generate significant static charges. The rolling contact with the substrate results in constant contact and separation of the surfaces which tribocharges both the substrate and the elastomer cleaning roller. The contact between the elastomer cleaning roller and the adhesive roll also generates more static charges on both the elastomer and the adhesive. In traditional systems both the elastomer cleaning roller and the adhesive roll are electrical insulators which do not allow the static charge to dissipate. As the charge builds up so does the associated field which can induce further static charges on the PCB's passing through the field within the equipment.

In the last few years in the PCB assembly industry a standard system for controlling static charges in the handling and transportation of sensitive devices has been developed, ANSI ESD S20.20. This system identifies four main failure models and places limits on the maximum voltages to which devices can be exposed. using each model. This standard also suggests approaches to be taken to ensure that the production environment can meet the specified limits.

As contact cleaning is used to clean PCBs with devices assembled onto them, it was vital to develop a cleaning solution which minimised the static charges generated without compromising the cleaning efficiency. The first step was to ensure that there was a very low resistance path to ground for all conductive components and then to use ionisation to reduce the charges on the PCB as it exits the equipment. The standard also recommends removing all non-essential insulators from the equipment. This posed a challenge as both the traditional elastomer roller and the adhesive roll are insulators but are also essential for the cleaning function.

The first stage reaching a solution was to reformulate the elastomer of the cleaning roller firstly by making it intrinsically semi-conductive to allow static to dissipate. Conductive additives could not be used due to the risk of their coming out of the elastomer and causing short circuits. When this proved to be insufficient to meet the standard, additional non-conductive additives were incorporated to allow the cleaning rollers to have the required surface resistance of $<10E9\ \Omega$. These additives were selected by using the triboelectric series to identify materials which might reduce the amount of tribocharging generated by the rolling contact. Standard triboelectric series are generally a list of materials in order of electro-negativity however Lee [4] has run tests on some material which give numerical values for the potential charge transfer. As can be seen from the extracts from his series in Table 4 Nanocleen elastomer running on polyimide has a very large tribocharging potential of 130nC/J while the Panel elastomer has a potential of only 2nC/J. By using carefully selected combination of additives both the required level of static dissipation could be achieved together with minimising the charges being generated. Table 5 shows the effect on the levels of static at various positions of the contact cleaning equipment while in operation with the original system having very much higher levels of charge than the new modified system which is compliant with ANSI ESD S20.20

Table 4. Tribo Electric Potential

Material	nC/J
Nano Elastomer	+60
Glass	+25
Epoxy PCB	-32
Polyimide	-70
Panel Elastomer	-72

Table 5. Static Charges

Position	Field Strength Original (V)	Field Strength Modified (V)
Elastomer roller (Entrance)	200	20
Elastomer roller (Exit)	500	20
Adhesive roll (Entrance)	2500	90
Adhesive roll (Exit)	3000	60

THIN SUBSTRATES

With the current drive towards electronic products which are thinner, lighter and more flexible has come the development of PCBs with similar properties. Inner layers as thin as 32 microns and copper foils at 12 microns are becoming much more common. When used in sheet format these materials pose significant challenges for contact cleaning technology. Firstly the copper surface is very chemically active having just been etched and has very high adhesion forces to the elastomer rollers. Secondly the substrate has very little stiffness to help it resist bending. The result of this is that the inner layer wraps around the elastomer rollers until the spring force generated by the bending of the material is sufficiently large to overcome the adhesion forces between the elastomer and the material. This wrapping mechanism generates damage to the material being processed and also causes significant production down time in automatic production lines. These disadvantages have until recently outweighed the benefits of the defect reduction of contact cleaning.

To overcome these issues a cleaning system had to be developed where the adhesion forces to the contamination would be great enough to allow the particles to be removed from the surface but that the adhesion to the copper/polyimide material would not cause the product to wrap.

Using the results of the research into the science of contact cleaning, it was possible to modify several of the forces of adhesion to allow the thin inner layers to be cleaned successfully. Firstly chemical modification was done to change the Van der Waals forces between the copper and the elastomer. Secondly the surface of the elastomer roller was texturised to increase the contact area between the elastomer and the particle of contamination while minimising the contact area between the elastomer and the substrate. The electrostatic forces were controlled using the recommendations of ANSI ESD S20.20 and the contact pressures applied by the elastomer rollers to the substrate minimised through the use of lightweight composite shafts.

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PROCESS STAGES

Contact cleaning can show benefits in defect reduction throughout the electronics supply chain.

According to S Heltzel [5] one of the causes of latent defects within the supply of high reliability PCBs is fibres within the base laminate. This can be due to fibres on the glasscloth before epoxy impregnation. Cleaning the cloth before it is coated can significantly reduce these defects.

If particles are present on the surface of polyimide before the material is wound into a roll the particles can become embedded into the polyimide due to the wind tension. Cleaning before winding reduces the risk of defects.

Cleaning before Dry film lamination was the original application for contact cleaning in the PCB industry and still remains a key area for defect reduction while contact cleaning before automatic inspection reduces false calls.

At the lay up process the uses of contact cleaning on press plates after scrubbing has become standard for many laminate producers and PCB manufacturers

Laser marking is a process which generates significant debris which can cause defects and contact cleaning is effective at removing the residual debris.

Contact cleaning should always be carried out immediately prior to the process which is sensitive to particles to prevent any risk of recontamination from the environment.

CONCLUSIONS

For decades contact cleaning has proved to be effective at reducing defects in electronics manufacturing. Through using the results of research into the forces of adhesion between different elastomers and other materials it has been possible to develop contact cleaning elastomers which can efficiently meet all the challenges of today’s materials while providing a platform for tailoring the systems to meet the cleanliness requirements for materials in the future

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